A 5-YEAR EXPERIMENT IN THE PREPARATION OF SEASONAL OUTLOOKS

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ABSTRACT

This report describes a method developed for routinely predicting the average characteristics of the forthcoming season from synoptic data gathered, processed, and analyzed on the macroscale. The method involves a combination of synoptic, statistical, and physical procedures and is at present partially, perhaps 60 percent, objective. The other 40 percent consists of experience in practical long-range forecasting, and thus involves imagination and ability to draw reasonable inferences from suggestive objective indications.

The method is illustrated by examples, and a verification of preliminary results is presented. In view of the short period the experiment has been in progress, the enormous complexity of the problem, and the fact that the research effort was largely skimmed off material and time primarily devoted to 5-day and 30-day outlooks, the conviction has been obtained that a greatly improved solution along the lines proposed is within grasp.

1. INTRODUCTION

Although numerous attempts have been made to foretell the character of the forthcoming season, there exists in the scientific literature no conclusive evidence that any person or group has materially succeeded. This is not meant to imply that many studies dealing with seasonal problems have been of little value—for the pioneering work of such figures as Walker [12] and his followers (e.g., Berlage [3], Schell [10],) Baur [2], Willett [13] and many others have thrown much light on these matters.

This situation, in which men who have spent a large portion of their life's work on the problem of seasonal weather forecasting often make great errors when venturing predictions, has encouraged large numbers of charlatans who at all times seem to have facile answers. This circumstance in turn has reduced the number of serious-minded and capable scientists who might have contributed.

It is hoped that the present work will be looked upon not as a suggestion for a general solution of a problem which in fact may have no such solution, but rather as evidence that an order exists in seasonal circulation and weather patterns—an order which holds out the hope that sometime in the future more sophisticated procedures may produce reliable forecasts. Even the elementary procedures treated in this report may offer a degree of skill possessing economic value. The methods have been developed largely through empirical means just as were those of 30-day outlooks [6], although a chain of physical (albeit qualitative) reasoning has guided the attack.

In short, the purposes of this paper are (1) to demonstrate that some degree of order obtains when the evolution of phenomena on a time scale of seasons is considered; (2) to describe a methodology designed to capture some of this order for purposes of seasonal predictions; and (3) to show through rigorous statistical verifications that some element of skill over and above climatological probability can be achieved even with the use of simple statistical-synoptic procedures.

2. CONCEPTS UNDERLYING THE METHODS OF PREDICTION

Most methods of long-range forecasting utilize only data observed in the atmosphere. This does not necessarily mean that the researchers involved believe that the physical causes of long-period phenomena are to be sought only within the atmosphere and that the seeds for future events are entirely contained therein. For example, Baur [2] and Willett [13], while primarily using atmospherically observed elements as predictors, have frequently indicated their belief in solar control of weather. However, their use of meteorological observations as the dominating data for analog selection or for statistical prediction implies that external effects are reflected in weather records sufficiently well so that predictions of some reliability may be made by sole reference thereto.

Similarly, in the case of methods to be described below, atmospheric records are considered as indicators of factors external to the atmosphere—but with the great difference that the external influences are very close at hand—in fact, at the surfaces of the oceans and continents. Thus feedback phenomena between abnormal sea and land surfaces, rendered abnormal by preceding prevailingly abnormal wind and weather systems, are believed to provide reservoirs of heat (or cold) and moisture upon which meteorological systems may feed. This type of interaction implies that the explanation of climatic fluctuations lies in the fact that on any time scale the systems making up the atmosphere's general circulation are always abnormal and that the underlying sea and land surfaces are also always abnormal. Since the longevity of the disturbed condition differs—especially between atmosphere and sea—there will be eternal oscillations or fluctuations in the circulations and characteristics of these media.

Of course, the response times vary tremendously in accordance with season, region, nature of the synoptic patterns in the atmosphere and oceans, etc. But if the forcing action of the surface boundary influences is sustained to affect in a similar way several synoptic systems over a period of time, then the mean state must differ from the normal. These anomalies may frequently be great enough to obscure even the forced perturbations induced by mountains. Thus in the treatment of abnormal states of the general circulation of the order of months, seasons, or years, we must consider not only the perturbations forced by mountains, coastlines, etc., but also those induced by abnormal surfaces.

In an earlier report the author [9] singled out some of the major influences of this type: namely, snow cover, sea-surface temperatures (especially their gradients), and surface moisture. Since these influences are geographically placed, it is likely that they will partially come to light in a statistical analysis of data gathered from the overlying atmosphere. However, one cannot expect appreciable dividends in this oversimplified attack because of the strong interdependence of each region with adjacent areas, and even with remote regions. This interdependence operates through complex dynamic and thermo-dynamic mechanisms in the atmosphere so that each disturbed area affects others—both disturbed and originally undisturbed. A further complexity arises because the secondarily disturbed portions retaliate by influencing the original area. In this manner we have great sustaining feedback loops not only between the atmosphere and the earth's surface, but also among various portions of the atmosphere.

As an example, we shall very briefly describe the type of interaction detailed in an earlier report [9], stressing the importance of extensive snow fields laid down in areas where and when snow was uncommon—namely over east-central portions of the United States in late spring. Cold air masses transported over the snow blanket were refrigerated (largely through the effect of changed albedo) and, on invading southern snow-free areas, were evidently still some 8° to 10° F. colder than they would have been had not the snow been present. The unusually cold regime over the Midwest and East assisted the rapid growth of cyclones along and off the east coast by virtue of the increased baroclinicity in an area where even normal horizontal temperature contrasts are great. Consequently, the major deepening of cyclones took place south of Newfoundland, and recurrent great cyclonic vortices there influenced the circulation downstream, helping create frequent blocking anticyclones near Iceland. These, in turn, helped block the deep storms south of Newfoundland.

Of course, this is an oversimplified account, for many more interactions were undoubtedly taking place during the same period of time within the atmosphere and between sea and atmosphere. But even if our explanation of events were the whole story, the correlation of any meteorological element at time lags greater than a few days would probably not be sufficiently large to warrant use of that element as the only tool for prediction. Certainly correlation of meteorological elements between two successive seasons of many years must be low when one considers the diverse flow patterns frequently encountered. Yet, in spite of this discouraging note, long-range researchers, including the present author, continue to make autocorrelation studies. The reason for this paradox lies not only in lack of understanding, but also in the fact that such autocorrelations show consistent patterns when large areas and large masses of data are treated. This consistency holds out the hope for ascribing physical causes for high autocorrelations in certain areas. It also makes it possible to use correlation indications selectively, placing more confidence in some areas than in others at certain times of the year. This partial solution gives the experienced long-range forecaster clues to phenomena in areas where indications are weak, for he can frequently piece together a coherent pattern from only fragmentary parts. In the large-scale sense this is essentially the problem of cross-correlations from which inferences may be drawn. It may also be looked upon as the utilization of synoptic-empirical knowledge involving patterns of quasi-stationary, long planetary waves characteristic of certain seasons and portions of the hemisphere.

The 700-mb. heights computed from regressions based on autocorrelations and portrayed as geographical fields over much of the Northern Hemisphere form one set of prognostic tools. Time lags are discussed below.

Another set of prognostic indications consists of temperature contingencies at one season lag based on seasonal Statewide temperature averages computed for a long period of record. These, too, are displayed on a base map so that spatial pattern and consistency may be evaluated.

In addition, basic synoptic material is processed in the form of seasonal mean charts of 700-mb. height and sea level pressure, and their departures from normal, as well as the associated thickness departures. Monthly mean components of these are also readily available in map form. Charts showing *annual* means of 700-mb. height and their departures from normal ending with each season are prepared and from these certain long-period trends are computed.

Finally, an attempt is made to keep track of the abnormalities of sea temperature, snow and ice fields, and, in the warm season, soil moisture.

All the above material is used in the preparation of seasonal outlooks. Examples of the use of this material are given below. We shall begin with the simplest procedure—the contingency method.

3. THE USE OF CONTINGENCIES

Linear coefficients of correlation and regression equations based upon them have numerous limitations. We shall not detail these, except to point out that in the case of temperature, persistence may be quite different for warm than for cold periods, particulary at certain times of the year. A contingency table will reflect this non-linearity while a simple correlation coefficient will not and may indeed suppress the information desired.

Since seasonal temperature anomalies are generally of very large scale (often embracing several States or even more than one-fourth of the United States), it is not necessary to use a fine mesh of stations to delineate temperature probabilities on base charts of the country. Furthermore, the use of many station records may not only lead to redundancy, but also, because of inhomogeneities in the station records, may even introduce undesirable "noise" in the large-scale picture. Therefore, the author and his former colleague, Mr. I. Enger, decided to employ a series of monthly average temperatures [11] for most of the 48 conterminous States.* These averages are generally available for about 60 years and occasionally for as much as 84 years. Although these averages employ variable numbers and distributions of stations according to State, it is unlikely that errors in the average would be large enough to invalidate their use for purposes of constructing 3×3 contingency tables as described below.

Thus each State's seasonal mean temperature was categorized into three equally likely classes denoted cold, normal, and warm. Contingency tables indicating the distribution of each season's classes following each immediately preceding season's class were constructed. For the sake of convenience these tables were transferred to geographical bases and expressed as excess or deficit in percent over the percentage expected by chance ($33\frac{1}{3}$). The entire set of contingencies is reproduced in figure 1. For example, in Texas cold winters were followed by cold springs 15 percent more often than a random population would yield, while both warm and moderate (normal) springs each occurred 7 percent less often than normally expected. Another example: in Arizona, warm summers followed warm springs 65 percent of the time (33+32), while warm springs were followed by cold summers only 5 percent of the time (28 less than 33) and by moderate summers 30 percent of the time (33 minus 3).

There are a number of interesting probabilities brought to light by the contingencies shown in figure 1, although the samples are too small to have statistical significance. Interesting features which emerge seem to call for physical explanations, some of which are qualitatively suggested below.

(1) In the western half of the nation and particularly in the southwestern quarter, both abnormally cold and warm seasons tend to persist. During colder seasons this may indicate the partial role of a conservative external factor like excess or deficient snow-cover as well as abnormal ocean temperatures in the upstream area off the west coast.

(2) In the East, neither cold nor warm winters tend to persist into spring. In fact, cold winters have a tendency to be followed by warm springs (and warm winters by normal springs) over the area from the Central Plains eastward to the Middle Atlantic States. The reasonably coherent non-persistent area runs counter to the general persistence found elsewhere and at other seasons.

(3) Cold summers tend to follow cold springs over much of the country, particularly over the Mid-West and Plains. On the other hand, warm summers tend to follow warm springs only over the western half of the country. The persistence over the Plains, as discussed in some detail in an earlier report on drought [8], may be due to the presence or absence of moisture in and on the soil. For example, heavy spring rains leave moist soil surfaces which utilize a good portion of the increased insolation of late spring and early summer in the process of evaporation, while dry surfaces respond more directly to sensible heating. Naturally, the moisture or dryness must be restored from time to time, but this restoration is accomplished periodically by cyclones or anticyclones generated by the surface abnormality. Contingency tables shown in the above-mentioned report show the joint effect of moisture and temperature. Especially in spring and summer, temperature and precipitation in the Plains are strongly correlated in a negative sense, so that the persistence comes to light in the temperature statistics.

(4) Both cold and warm summers tend to persist into the fall over the Far West, and especially in southern portions. Perhaps oceanic effects are operative here, but in a highly complex way. The offshore influence of the ocean in summer operates in quite a different manner than in winter, for the inland air flow is comparatively weak in summer and fall. However, variable ocean temperatures off the coast (due to variable upwelling) could provide variable horizontal temperature contrasts in different years between western States and the sea, and these contrasts, in turn, might force characteristic circulations which recur in the same season. For example, the existence of colder than normal offshore waters might result in an increase in thermal contrasts between land and sea thereby favoring an increase in the strength of the western upper-level anticylcone with its associated warmth at the surface. In other words, part of the mechanism for creating and maintaining the western upper-level anticyclone may lie in the sea-land contrast which determines indirectly the strength of the southerly thermal (and real) wind in mid-troposphere in this area in summer.

(5) Cold falls, and to a lesser extent warm falls, tend to persist into winter over the Pacific Northwest. This is

*In cases of small States like those in southern New England, a few States were grouped together to form an average.

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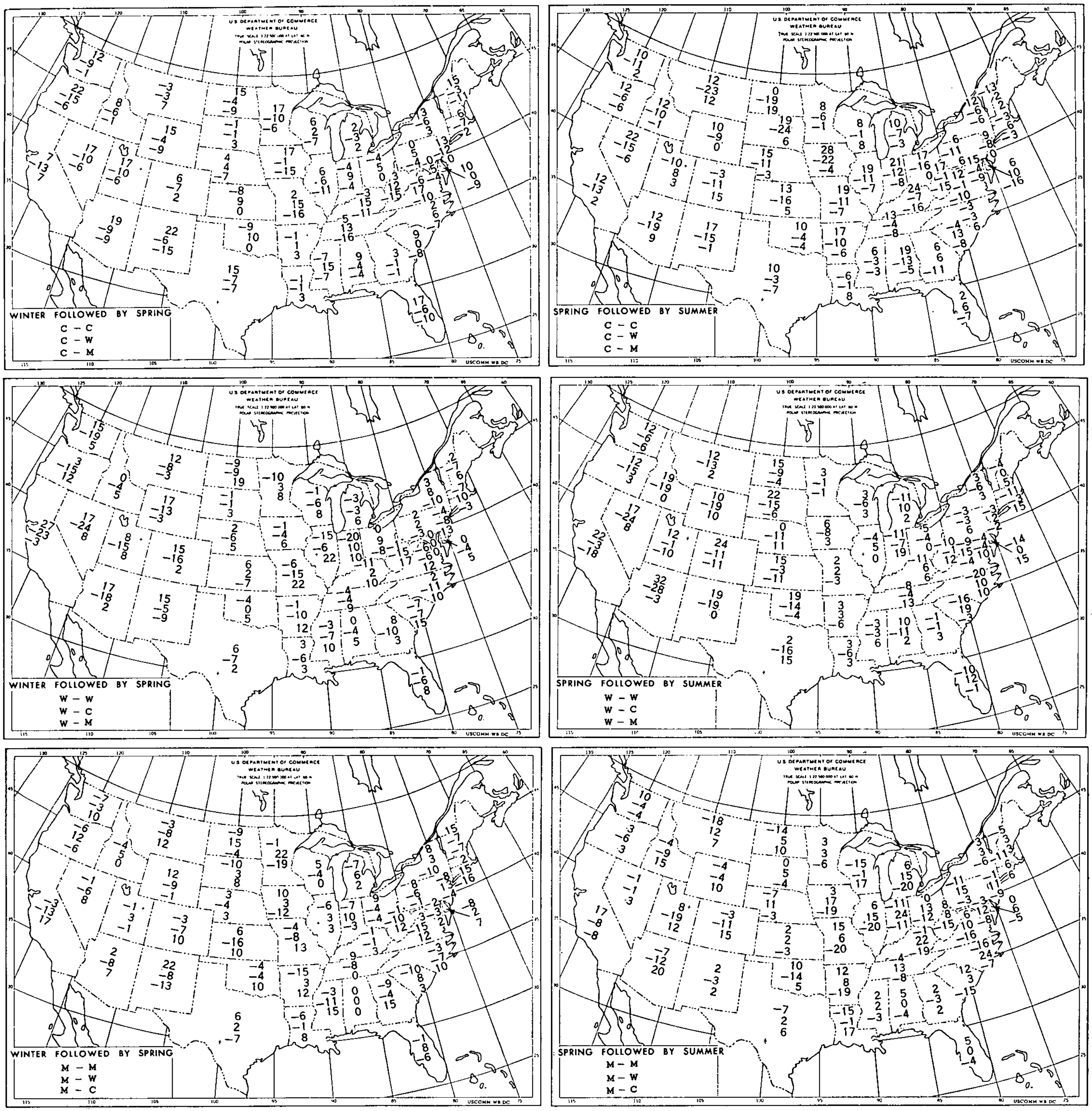

FIGURE 1.—Contingencies of seasonal temperature anomalies by States. Numbers give excess or deficit in percent over expected (33⅓ percent) in the three classes, cold (C), warm (W), and moderate (M), following the class observed in the antecedent season. For example, using the key in the lower left box of the left chart, it may be seen that cold winters in Texas tend to be followed by cold springs 48 percent (33+15) of the years, by warm springs 26 percent, and by moderate springs 26 percent.

another area where complex ocean–land contrasts may operate. In addition, snow (or its absence) at higher elevations may play a role in causing the persistence.

Practical use is made of the contingencies given in figure 1 in plotting on a base map of the United States the most likely temperature class to arise in each area along with its percent excess over chance. Such a plot for the fall of 1959 (based on the preceding summer's

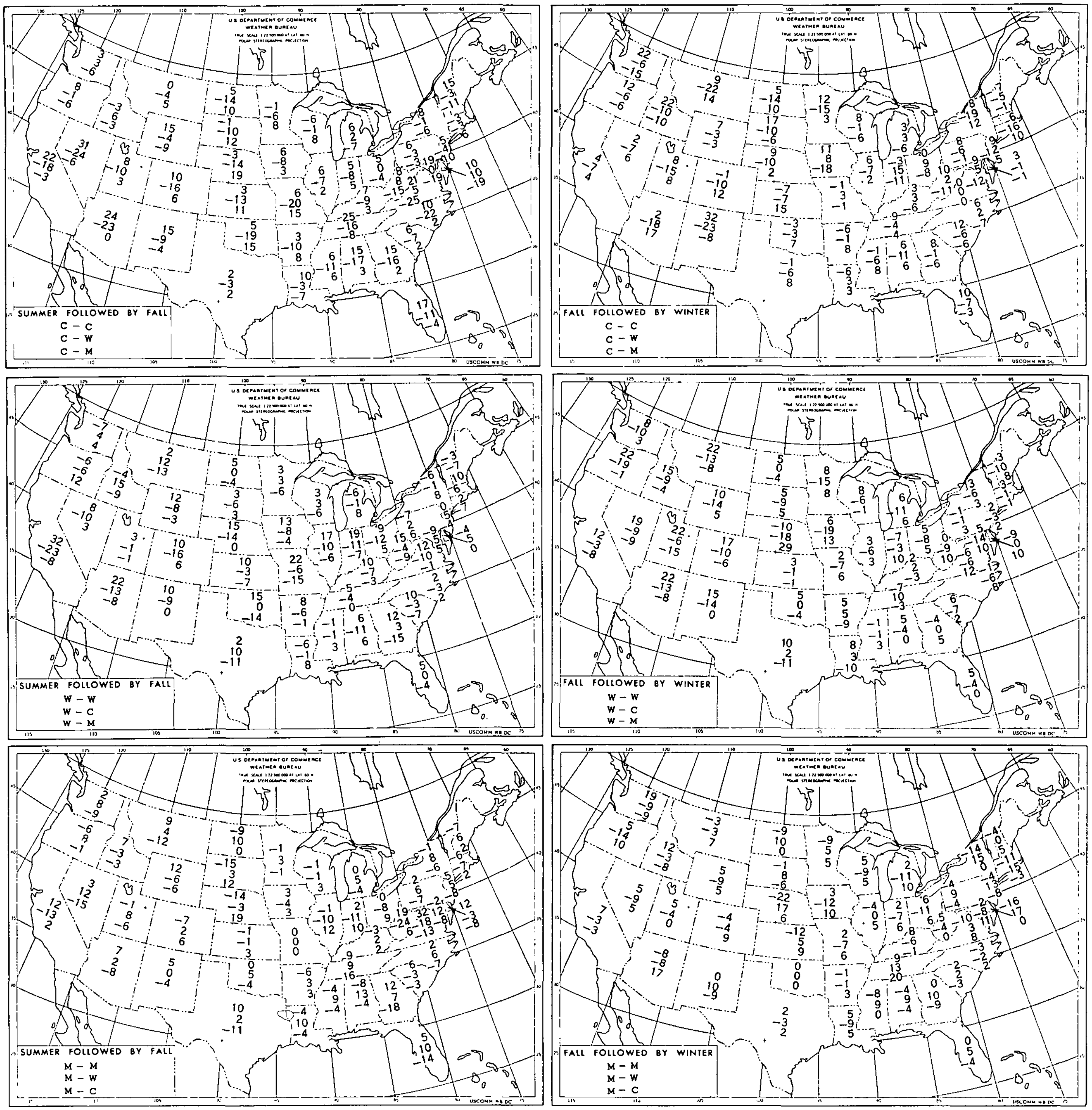

FIGURE 1.—Continued.

temperature classes) is shown in figure 2, and an attempt has been made to group adjacent similar indications into large coherent areas. This synthesis, while not always straightforward, requires some elimination of isolated indications but nevertheless brings out reasonably consistent nationwide patterns of temperature anomaly. In figure 2, for example, the pattern of warmth in both the East and West is interrupted by a belt of cold air through the Plains.

These patterns of temperature anomaly frequently suggest the general character of the circulation and synoptic activity apt to prevail. These inferences may include zones of more frequent than normal cyclonic activity (usually occurring between a pool of cold air and

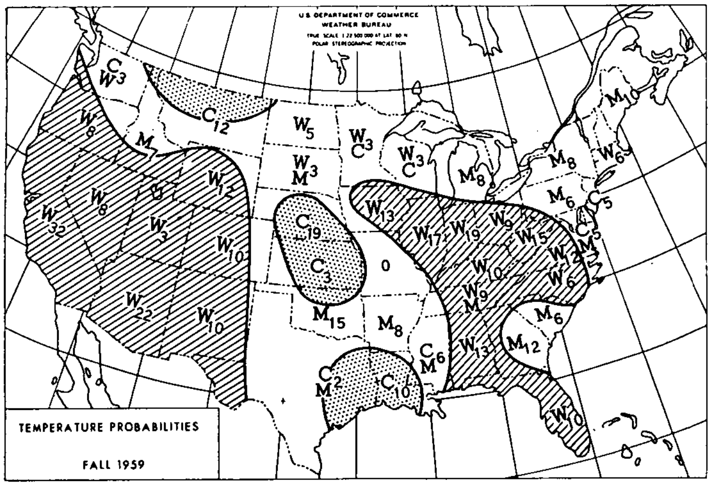

Figure 2.—Most likely temperature classes and the percentage excess over expected (33⅓ percent) for fall 1959, as determined from figure 1 and the observed temperature anomalies for summer 1959 (not shown).

one of warm air to its east) as well as prevailing paths of polar anticyclones (in the belts of below normal temperature).

It must be stressed that these contingencies form only one set of tools used in the preparation of seasonal outlooks. They are used most effectively when considered along with other procedures discussed below. Then again, the degree of confidence placed on contingency patterns varies not only with their agreement or conflict with other indications, but also with their large-scale coherence, their excess percentages over chance, and the frequency of indicated seasonal patterns determined from a catalog similar to the classification system used for 30-day anomalies [6].

It is noteworthy that even if one used only the contingency method on a countrywide basis, he would probably achieve an economically valuable degree of skill—assuming, of course, that the statistical characteristics in this 60-yr. period will be reproduced in the new (independent) data sample. The percentage excess over chance obtained for the dependent data sample is shown for each season and State, and in the average for all seasons in figure 3. The figures on these charts have been obtained by adding up for each State the highest positive numbers for each of the three categories and then dividing by 3. Hence, for New Mexico, taking spring as the subsequent season, we add 22 (following cold winters), 15 (following warm winters) and 22 (following moderate winters), thereby obtaining a sum of 59, which, when divided by 3, averages about 20 percent above chance (33⅓ percent). It must be stressed that this skill cannot be attributed solely to persistence. Persistence skills (not reproduced), while similar in some areas, are *lower* in most.

It is at once apparent from figure 3 that the nationwide average for each of the seasons is positive:

Indications for—

Winter (i.e., based on fall)	9. 9 percent over expected
Spring	10. 6
Summer	12. 1
Fall	10. 4
Average	10. 8

It is readily seen that the contingencies work out best for the southwestern quadrant of the Nation and in a zonally oriented band running eastward from the central Plains through the middle Atlantic States. This geographic distribution, highlighted by the chart representing the average of the four seasons, may suggest season-to-season persistence of a southward or northward displacement of the westerlies (and polar front) from its normal position, as well as the oceanic effects on the West described earlier. In turn, the persistence of the position of the westerlies over the United States might be partially determined by the nature of the land surfaces (as well as by oceanic factors). We refer here to such factors as the presence or absence of snow cover in the colder months, especially in areas where the climatological probability of snow is marginal, and the dry or moist character of the soil [8] during the warm half of the year.

4. USE OF MID-TROPOSPHERIC DATA

By making use of data extracted from mean 700-mb. charts for a grid of points, it is possible to compute correlation coefficients at lag and thereby obtain regression equations for each point. Isopleths drawn on the map on which the correlations are plotted bring to light large-scale fields of high correlation. The fields are of large scale because mean 700-mb. anomaly fields on which the correlations are based are of this scale. Consequently, it is not necessary to work with a fine grid.

General characteristics of the fields of lag correlation based on seasonal means with one season lag were described by the author [7]. In addition to properties of scale, it was demonstrated that a latitudinal dependence existed, not unlike the form of normal latitudinal profiles of 700-mb. height. The data showed high positive correlation at low latitudes, diminishing rapidly poleward of the subtropical anticyclones. This observation, plus an apparent seasonal migration of the belt of maximum correlation paralleling the subtropical high-pressure belt, suggested that the latitude dependence may reflect a pressure dependence (a fact also brought to light in studies of persistence of sea level pressure by Landsberg, George, and Appel [5], and given qualitative physical interpretation by the author [7, 8]).

The latest series of seasonal lag correlations at the 700-mb. level based on the period 1933–1962 is shown in figure 4. Although these contain about five more years of data than those published earlier [7], they show essentially the same patterns. Unfortunately, the earlier years (the 1930's) are based on maps which, because of sparse data, had to be constructed by extrapolation from

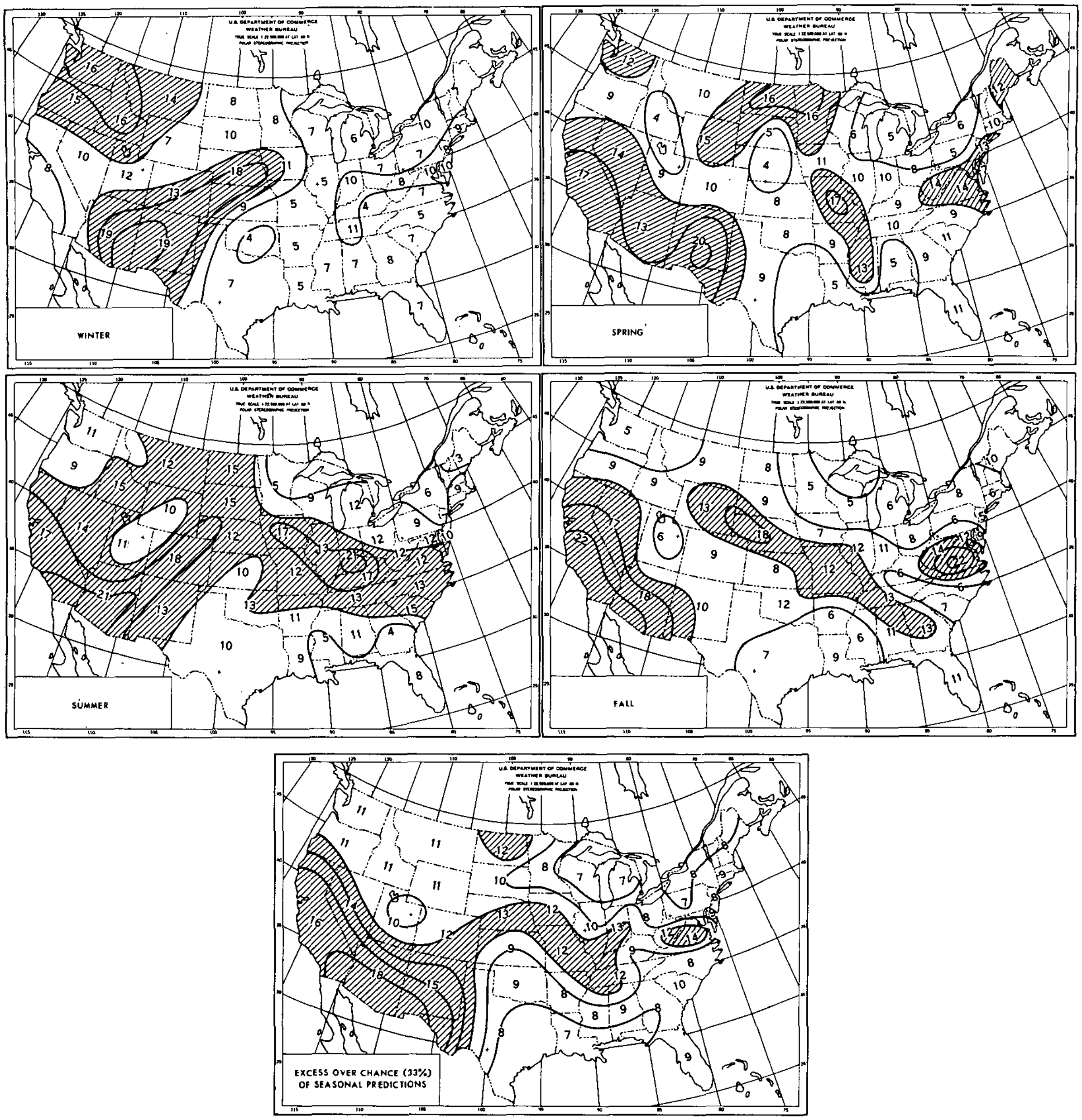

FIGURE 3.—Excess over expected (in percent) of seasonal contingencies for each season and for all four seasons (lowest chart) during the 60–80-yr. period of dependent data. Shading denotes areas of values greater than 12 percent excess. Isopleths drawn for every 4 percent.

sea level pressures for areas outside the United States. Thus, there are bound to be errors. A separate set of charts (fig. 5) was worked up for the more recent period 1948–1962 when data were more reliable and abundant. While there are some differences between the maps of figures 4 and 5, perhaps indicating secular changes, they do not seem to be great. The charts in figure 5 were constructed using electronic computers and a finer grid (10° rather than 20° of longitude at each 10° latitude), and embrace much of the Northern Hemisphere. Although the sample of data is small, involving only 15 years, the charts probably reflect some aspects of more recent persistence better than those for the longer periods.

The practical application of this material consists of using the point-by-point regression equations to indicate values which may characterize the forthcoming season. These height anomalies are then plotted on a chart and isopleths drawn to depict a field of anomalous flow. As with the contingencies, it is hoped that the sequences developed in the dependent sample of data will be reflected in new data.

Two such prognostic charts of anomalous flow are prepared from the regression equations—one based on the long-period sample and the other on the 15-yr. sample. At the conclusion of each season the regression coefficients are reworked to include the new season's data. Arrows

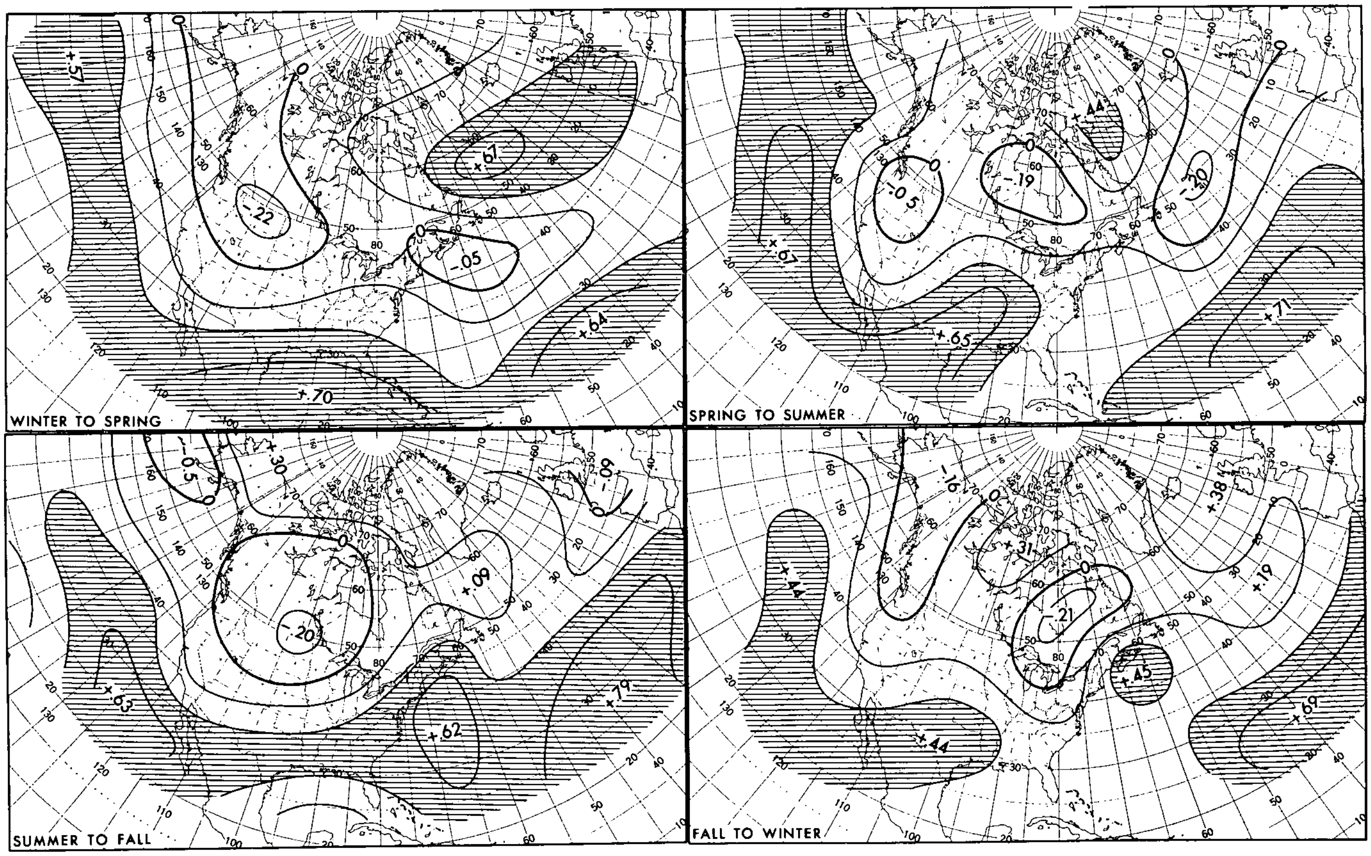

FIGURE 4.—Correlations of 700-mb. height anomalies at one season lag for the period 1933–1962. Isopleths drawn for each 0.20. Shaded areas exceed the 3 percent level of significance.

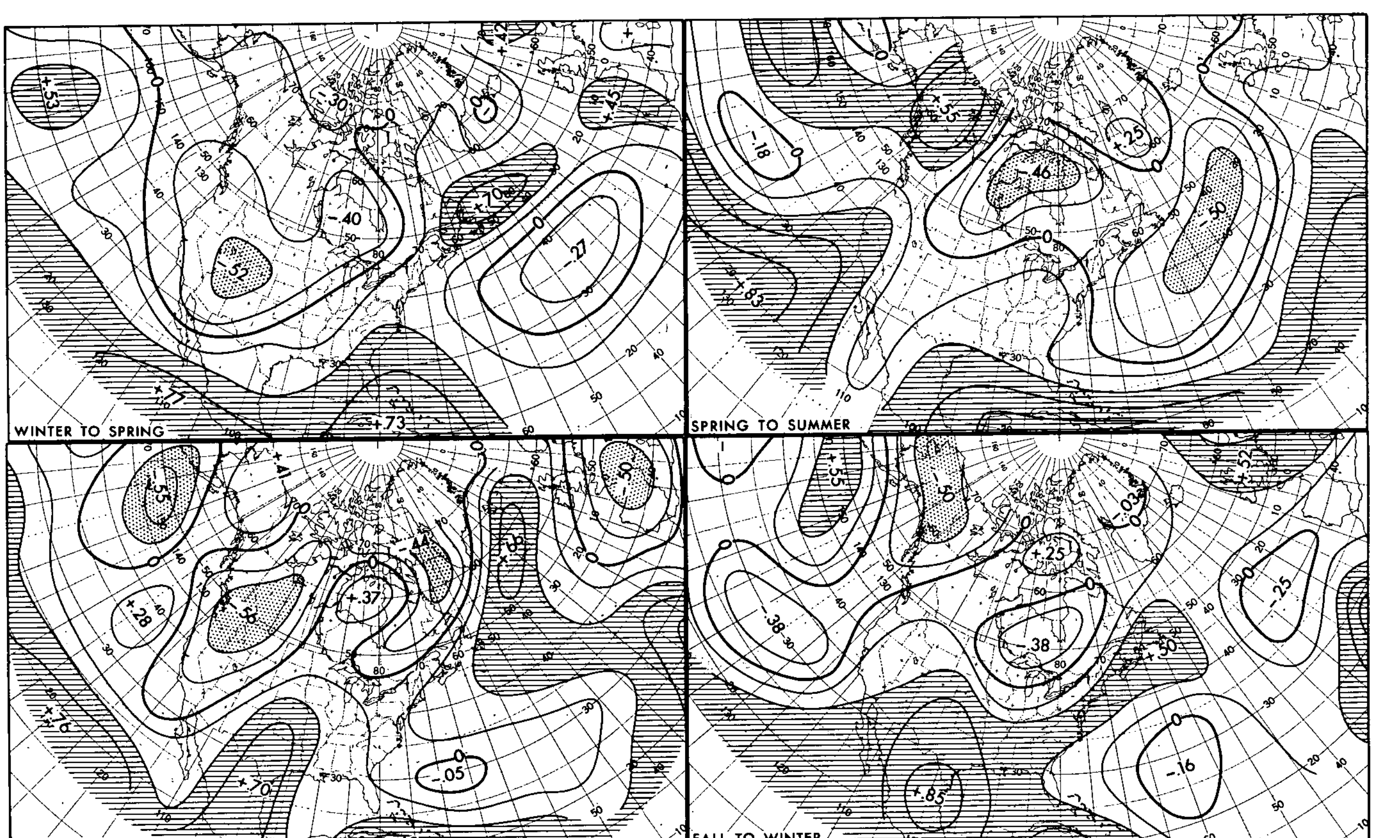

FIGURE 5.—Same as figure 4, except for the period 1948–1962.

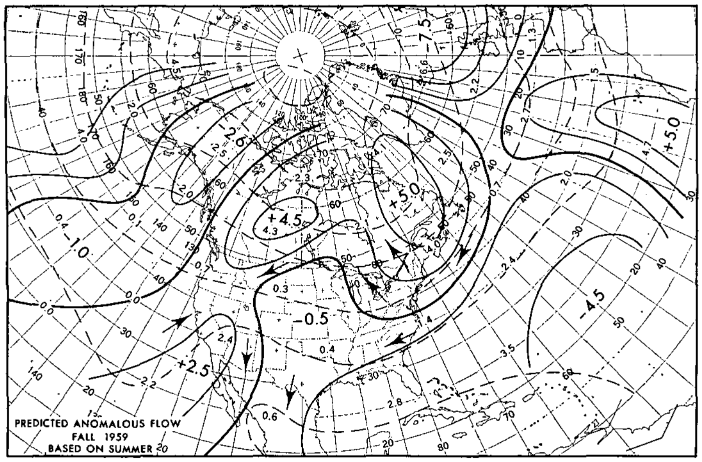

FIGURE 6.—Isopleths from results of regression equations (based on the correlations of fig. 4) indicating the possible distribution of 700-mb. height anomalies for fall 1959. Isopleths are drawn for each 20 ft., arrows imply anomalous geostrophic component of flow, and broken lines represent normal summer thickness isopleths between 1000 and 700 mb.

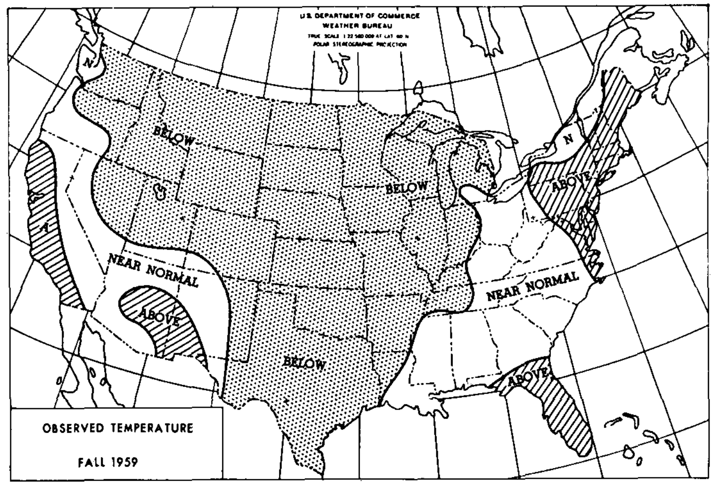

FIGURE 7.—Observed temperature anomalies for fall 1959, expressed in three categories.

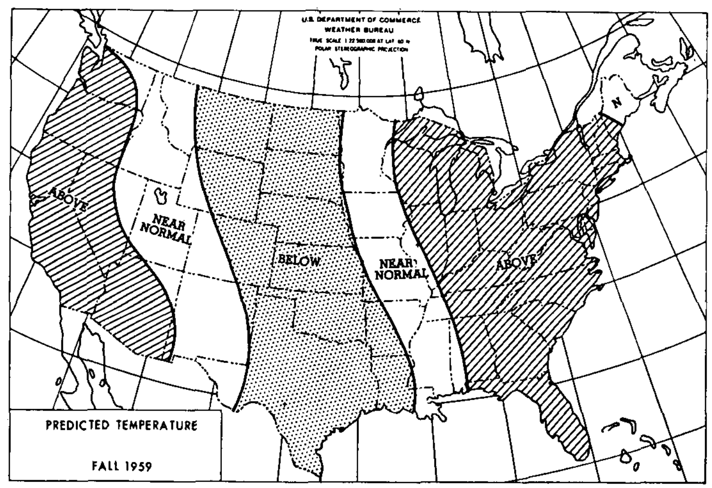

FIGURE 8.—Temperature anomalies predicted for fall 1959.

showing the direction of anomalous flow are usually indicated along or between the isopleths, for this flow component, in addition to its absolute value, is believed highly important for purposes of seasonal prediction. In fact, the computed anomalies are generally only about one-fifth the magnitude of the observed anomalies, largely because of the lowness of the correlations.

An example of a field of isopleths computed from regressions for summer to fall in 1959 is shown by the solid lines of figure 6 where the arrows show the probable anomalous wind components. Broken lines in this figure represent the normal *thickness* isopleths for the central fall month of October. Noting the indicated angles of intersection between the solid and broken lines and taking into account the general relationship found and used in extended-forecasting practice [6], namely that positive anomalies and anticyclonic curvature are associated with above normal surface temperature (negative and cyclonic curvature with below normal surface temperatures), we can obtain a rough idea as to which areas might be dominated by warmer or colder than normal air masses. In this special case the East (especially the Northeast) would be expected to be warm because of (a) prevailing transport of air from more southerly areas than is normal and also from the relatively warm ocean, (b) anomalous subsidence suggested by the anticyclonic curvature, and (c) positive height anomalies. On the other hand the Great Plains would be expected to be cool as a result of indicated anomalous transport, anomalous cyclonic curvature, and negative anomalies. In the Far West, especially the Southwest, positive anomalies of surface temperature are suggested. It is of interest to compare these indications with both the contingencies for the same season (fig. 2) and the temperature anomalies actually observed (fig. 7)*.

The prediction actually made for fall 1959, based largely on this material, but also on other considerations, is shown in figure 8.

Using similar reasoning and utilizing the indicated anomalous flow, the contingency chart, *and the predicted temperature pattern*, it is also possible to estimate the gross aspects of the precipitation pattern—whether heavy, moderate, or light. Thus, in this case, in and to the east of the anomalous cyclonic zone over the Plains, heavy precipitation is suggested. The *predicted* horizontal temperature contrasts, wherein prevailingly warm air lies to the east of cold, also imply more than normal cyclone formation and development, and thus substantial precipi-

*The observed pattern for the first two fall months, September and October (not reproduced), was in better agreement with the predictions since most of the area east of the Lower Mississippi and Great Lakes averaged above normal.

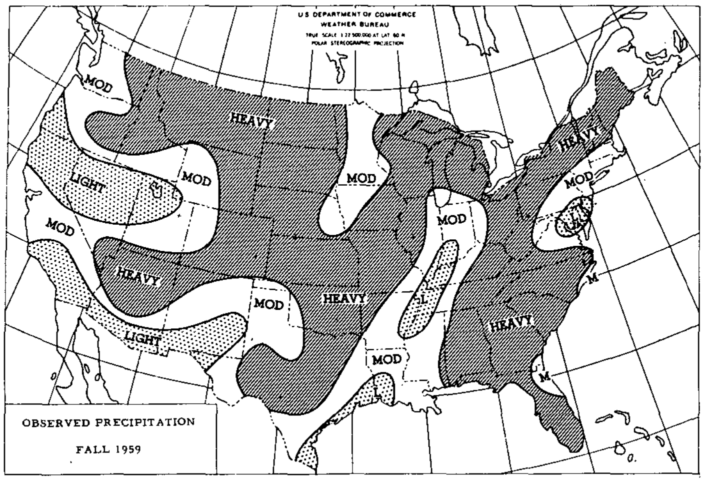

FIGURE 9.—Observed precipitation anomalies for fall 1959, expressed in terms of three classes, light, moderate, and heavy.

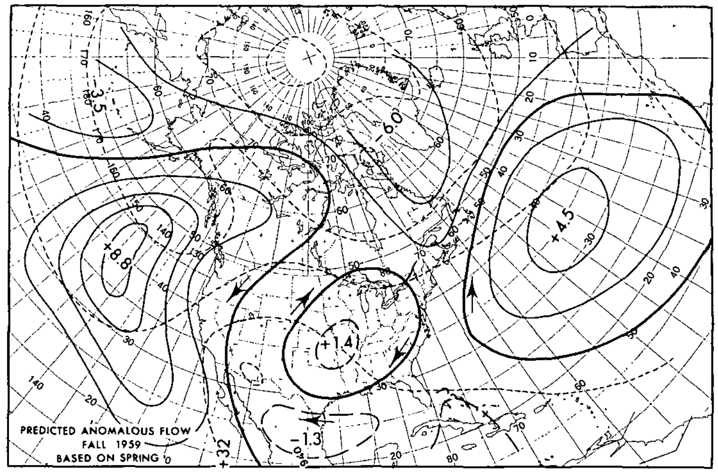

FIGURE 11.—Anomalous flow implied by regression-computed isopleths for summer 1959, based on spring 1959 (see fig. 6 and text for detail).

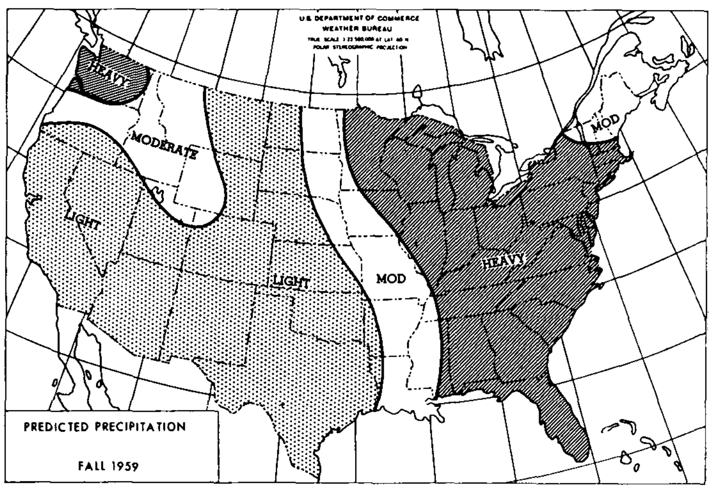

FIGURE 10.—Predicted precipitation classes for fall 1959.

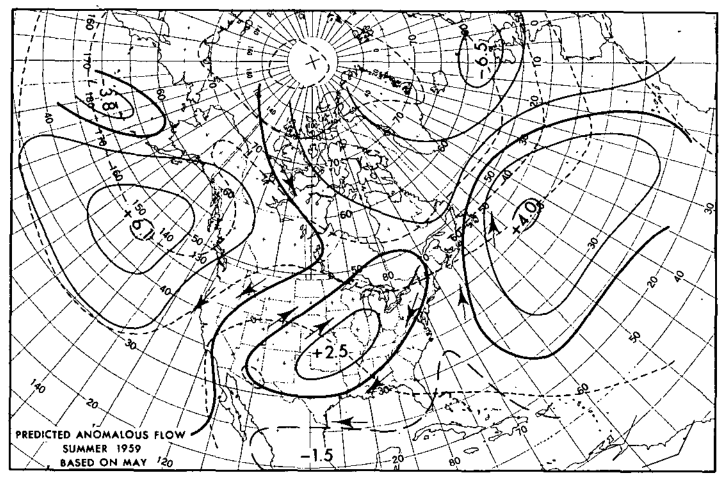

FIGURE 12.—Same as figure 11, but computed from observed anomalies for May 1959.

tation. On the other hand, the Far West might be expected to be dryer than normal over most areas as suggested by the configuration and sign of the anomaly isopleths and also by the sinking air motion implied by the angle between isopleths of anomaly and normal thickness lines. The observed classes of precipitation for fall 1959 are shown in figure 9, and the prediction in figure 10.

This example is chosen only to demonstrate a highly general relationship. Computations using regression equations with other lags than a season are also made. For example, there are frequently breaks in large-scale weather regimes between April and May and especially from October to November, as pointed out by the author [7]. Therefore, regressions between May and the following summer, and between November and the following winter, have been computed and prognostic maps of the type described above are also prepared. If these agree reasonably well with the season-to-season lag charts, one's confidence is strengthened. On the other hand, disagreement may force the forecaster to decide how much to weigh the last month's indications against those computed from the longer period. He is assisted here by the 30-day outlook made about the same time as the seasonal prediction, for this may suggest that the past month's regime was transitory and not indicative of a quasi-permanent pattern. He is also assisted by the pattern given by the contingencies, and by certain synoptic trends to be discussed later.

An example of two prognostic anomalous flow charts, one based on regressions from spring to summer 1959 and the other from May to summer 1959 is shown in figures 11 and 12. Note that while the two patterns are quite similar over most areas, the anticyclonic curvature of the anomalous flow lines is stronger over northeastern United States on the chart based on May. This area was therefore placed in the above normal temperature category (fig. 13) in opposition to the contingency estimates (fig. 14) which were unorganized and confused over the Northeast. Note that in other areas (e.g., the Far West and the Gulf States) all sets of indications are in substantial agreement.

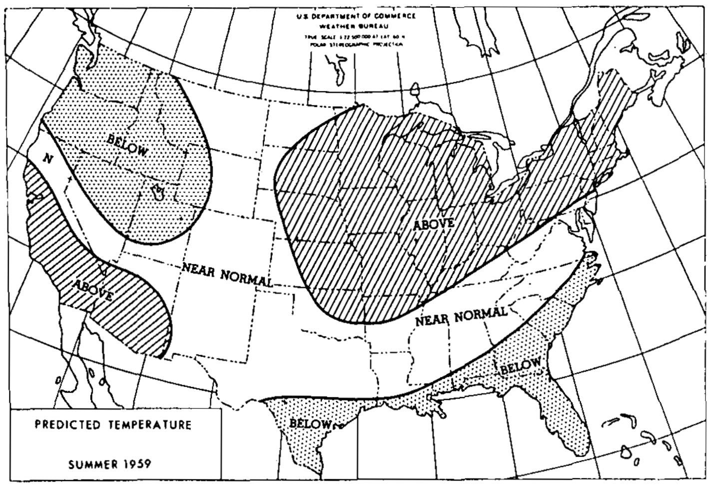

FIGURE 13.—Final temperature prediction made for summer 1959.

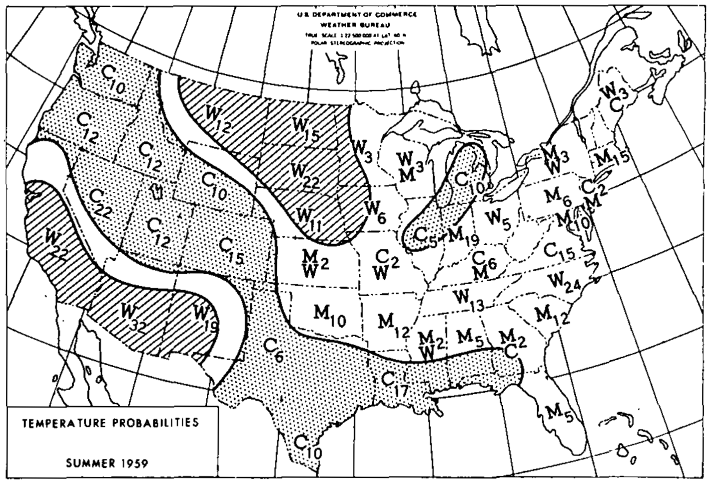

FIGURE 14.—Temperature class contingencies for summer 1959, based on figure 1 and observed pattern for the preceding spring temperatures.

The comparison of final predicted with observed temperatures (figs. 13 and 15) shows a fairly good forecast, considering the present state of the art. The principal failure is over the western Plateau where above normal was observed rather than near and below normal as predicted. Even here, however, the temperature just barely reached the above normal category, with larger departures in California and the Northern Plains, as roughly suggested by the predicted gradients and the contingencies. The precipitation forecast and the observed pattern for this summer are shown in figures 16 and 17.

Regressions are also worked up between the same seasons of successive years. Naturally, these are given less weight than the other more immediate indications. However, clusters of successive winters (or other seasons) with similar characteristics frequently arise, and if the year-to-year indications line up with the other more up-to-date suggestions based on the past season, one's confidence is strengthened.

Besides this material, 700-mb. data are also worked up into annual means and their departures from normal. This is done at the end of each season and frequently illuminates long-period climatic fluctuations lasting more than one year. From these annual charts it is also possible to construct an "annual trend chart" assuming a linear trend in these annual means constructed each season. From such an assumption it can be shown that the height changes between the season just ended and the corresponding season one year previous will also take place between the season to be predicted and its corresponding season one year previous. In other words if F and W represent 700-mb. heights in fall and winter, and the subscripts refer to years:

$$W_{62-63}=F_{62}-F_{61}+W_{61-62}$$

Charts of this parameter are occasionally remarkably good prognostications, as was the one shown with its verification (figs. 18 and 19) for the highly abnormal winter

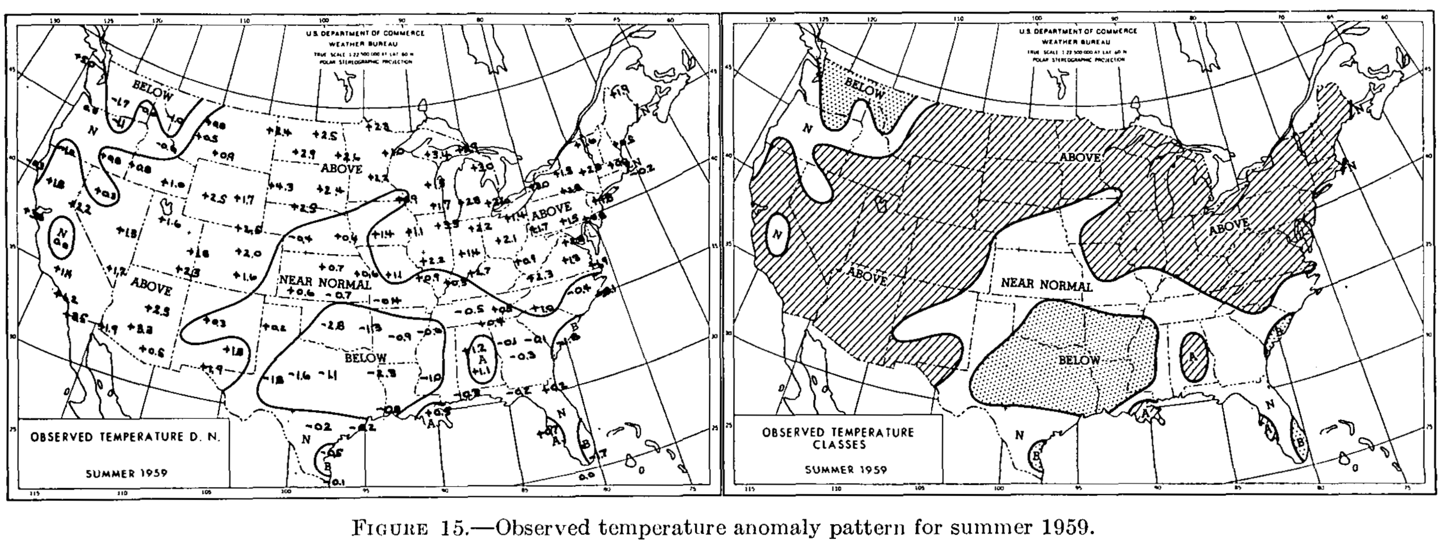

FIGURE 15.—Observed temperature anomaly pattern for summer 1959.

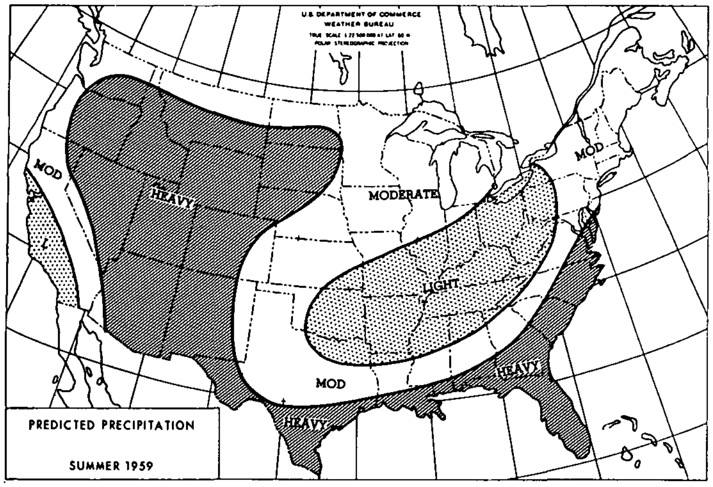

FIGURE 16.—Precipitation classes forecast for summer 1959.

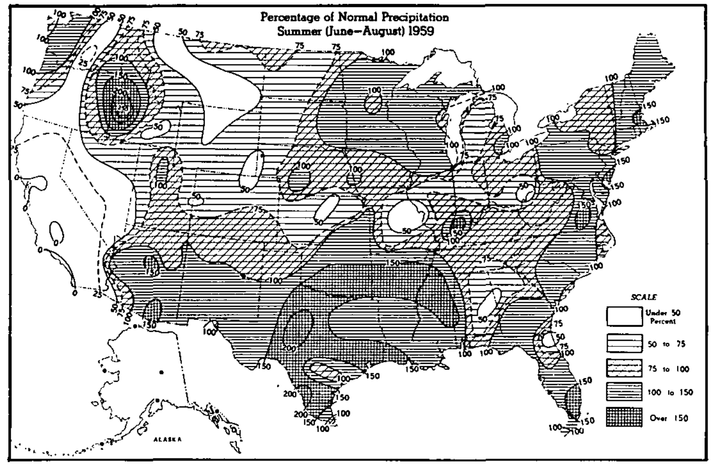

FIGURE 17.—Observed precipitation, expressed in percent of normal, for summer 1959.

of 1962–63. Such correspondence is unlikely to result by chance and probably represents some long-lived external constraints (perhaps surface abnormalities) which force the wind and weather patterns.

5. SYNOPTIC DISPLAY

Just as with short- or medium-range forecasting, it is important that the seasonal forecaster be familiar with the circulation and weather patterns on many time scales up to the time he makes his prediction. In our experience an effective visual display of the following mean seasonal charts for the past five seasons has been helpful in providing background:

700-mb. height with its departure from normal superimposed.

Sea level mean pressure with its departure from normal superimposed.

1000–700-mb. thickness departure from normal.

Surface air temperature departure from normal (analyzed into classes) for the United States.

Total precipitation at many stations over the United States (analyzed into classes).

These charts are placed on one wall of a room whose opposite wall contains all the charts used in the preparation of 30-day outlooks. In this manner the interdependence of phenomena with different time scales is brought into sharp focus. Besides, with this display it is at times possible to observe trends over months or even seasons, as well as to note persistent and non-persistent regimes.

The long-range room also contains a convenient archive of maps and data from past months and seasons as well as many synoptic-climatological aids. This material makes it possible to seek out analogs. Although this is done routinely the method is given little weight in the preparation of the seasonal outlooks, for the sample for selecting analogs is not large and it is felt that the methods described earlier capture more effectively the prognostic value of the past record.

Finally, as part of the experiment, an attempt is made to keep track of the abnormalities of snow and ice cover, of surface ocean temperatures over the Pacific and Atlantic, and soil moisture over the United States in a manner detailed in a report by Dickson [4]. It is hoped that ultimately these considerations will enter into a quantitative numerical forecasting model such as proposed by Adem [1].

6. VERIFICATION OF SEASONAL OUTLOOKS

In any experiment such as described it is imperative that a rigorous verification be made, for it is often easy to be carried away by the success of a few forecasts or, on the other hand, to become overly pessimistic because of certain failures. Therefore, an objective system was established to gage the skill of the forecasts with respect to climatological probability and also with respect to persistence (i.e., assuming that the anomaly pattern of the past season is used as a forecast for the next).

The verification was carried out for 100 stations (fig. 20) roughly equally spaced. For each season monthly mean temperature anomalies and total precipitation amounts were tabulated. Standard deviations for the monthly mean temperature (kindly supplied by H. C. S. Thom) were then used to arrive at a reasonable figure for seasonal standard deviations taking into consideration the correlation observed between adjacent months.

From these values, class limits for above, below, and near normal were determined for each station and each season (equally likely categories). The seasonal precipitation totals were arrayed and limits were easily determined for the three equally likely categories: light, moderate, and heavy.

The above limits were then used to verify the experimental predictions and those made by persistence. The conventional skill score

$$\text{Skill} = \frac{\text{percent correct—percent expected by chance}}{\text{100—percent expected by chance}}$$

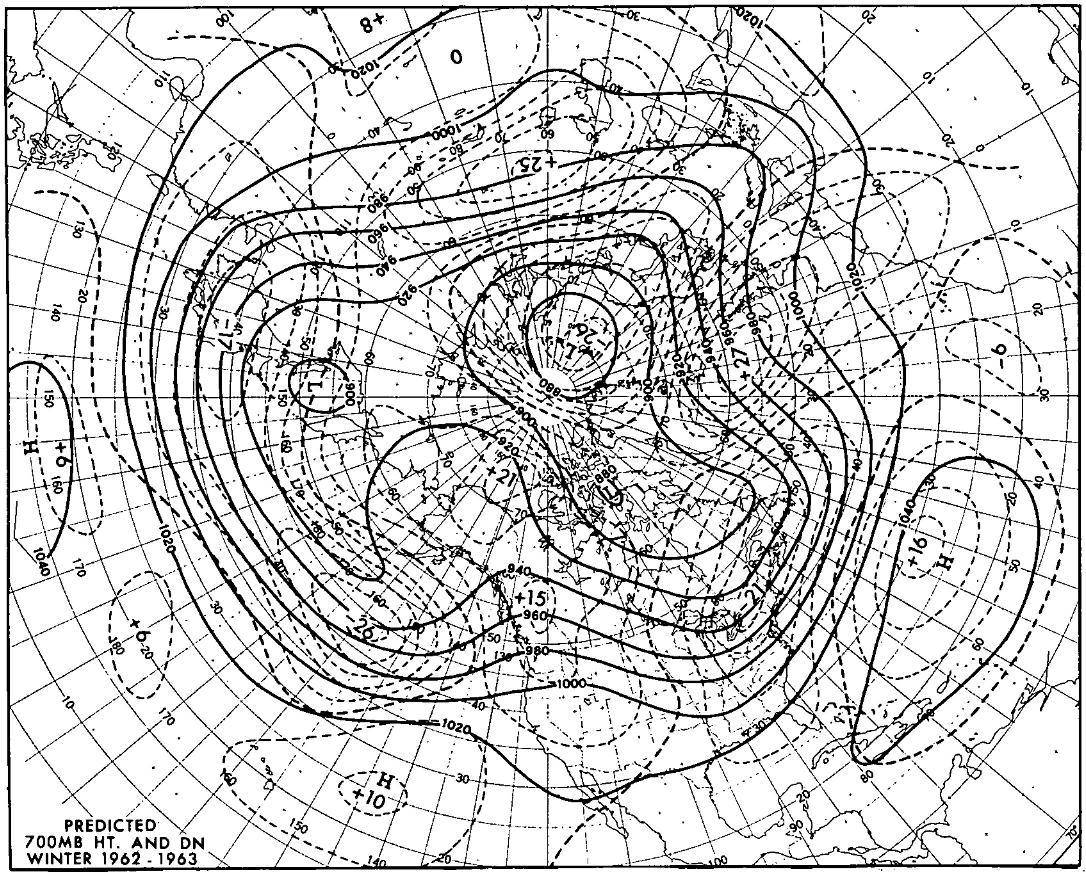

FIGURE 18.—Predicted 700-mb. contours (in tens of feet) and departure from normal predicted for winter 1962–63 by assuming linear extrapolation of overlapping annual means of seasonal departures (see text for details).

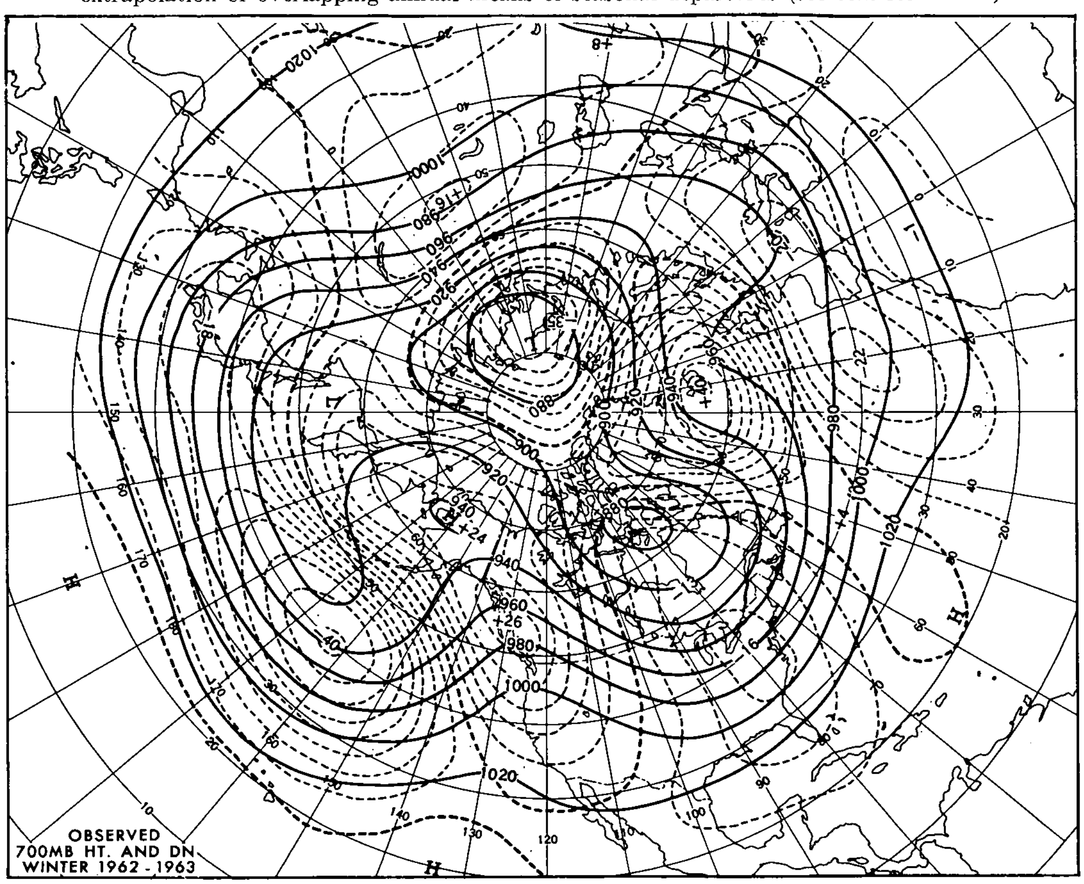

FIGURE 19.—Observed 700-mb. contours (in tens of feet) and departures from normal for winter 1962–63.

was employed. A tabulation of the scores for 22 seasons beginning with winter 1958–1959, the beginning of the organized experiment, is shown in table 1. In the average it appears that both temperature and precipitation forecasts possessed positive skill over climatological probability; and, particularly for temperature predictions, over persistence. A contingency table of observed vs. forecast classes for the 2200 predictions (22 seasons$\times$100 stations) is given in table 2. Table 3 shows the probability of achieving a forecast class for this data sample. Table 4, giving the distribution of skills by seasons, shows that spring was the most difficult to predict and also the least persistent. Examples of a good, average, and poor temperature forecast, based on table 1, are shown in figures 21, 22, and 23.

At the author's request, Dr. Joseph Bryan, Consultant at the Traveler's Research Center, tested the statistical significance of these results. The data furnished him consisted of the final forecast and persistence skill scores along with the contingency tables for each of the first 19 seasonal temperature and precipitation forecasts for the 100 stations shown in figure 20.*

From this material Dr. Bryan found that for the purposes of determining degrees of freedom it could be assumed that 1 station out of 11 can be taken as independent for the verification of temperature anomalies and 1 station out of 4 for precipitation anomalies. These

*When the material was submitted to Dr. Bryan, only 19 verified forecasts were available. Later, when three new verified predictions were added, the scores were not materially altered, although they improved slightly—especially with respect to persistence (see table 1).

TABLE 1.—*Seasonal forecast skill scores*

	Temperature		Precipitation	
	Forecast	Persistence	Forecast	Persistence
1959 Winter	31	−6	17	7
Spring	−2	−16	22	−3
Summer	16	34	2	7
Fall	30	−4	17	−6
1960 Winter	10	12	4	16
Spring	8	−11	−33	−4
Summer	10	16	22	5
Fall	0	12	−10	−1
1961 Winter	40	−6	−4	−7
Spring	−18	17	8	−9
Summer	7	12	14	−10
Fall	48	−14	6	0
1962 Winter	−2	19	2	16
Spring	−2	7	12	2
Summer	13	−2	2	8
Fall	−26	4	−14	−9
1963 Winter	14	19	14	−9
Spring	1	−38	−5	2
Summer	20	20	−6	13
Fall	−2	3	−8	−3
1964 Winter	−3	−20	25	4
Spring	39	−11	1	−15
Average (22 seasons)	10.5	2.1	4.0	0.2

TABLE 2.—*Contingency tables for seasonal temperature and precipitation forecasts for the period winter 1959 through spring 1964 (22 seasons)*

		Temperature forecast						Precipitation forecast			
		Below	Normal	Above	Total			Light	Moderate	Heavy	Total
Observed	Below	382	261	191	834	Observed	Light	239	248	251	738
	Normal	201	191	197	589		Moderate	188	247	293	728
	Above	223	240	314	777		Heavy	181	233	298	712
	Total	806	692	702	2,200		Total	608	728	842	2,178
	Skill=+10.5						Skill=+4.0				

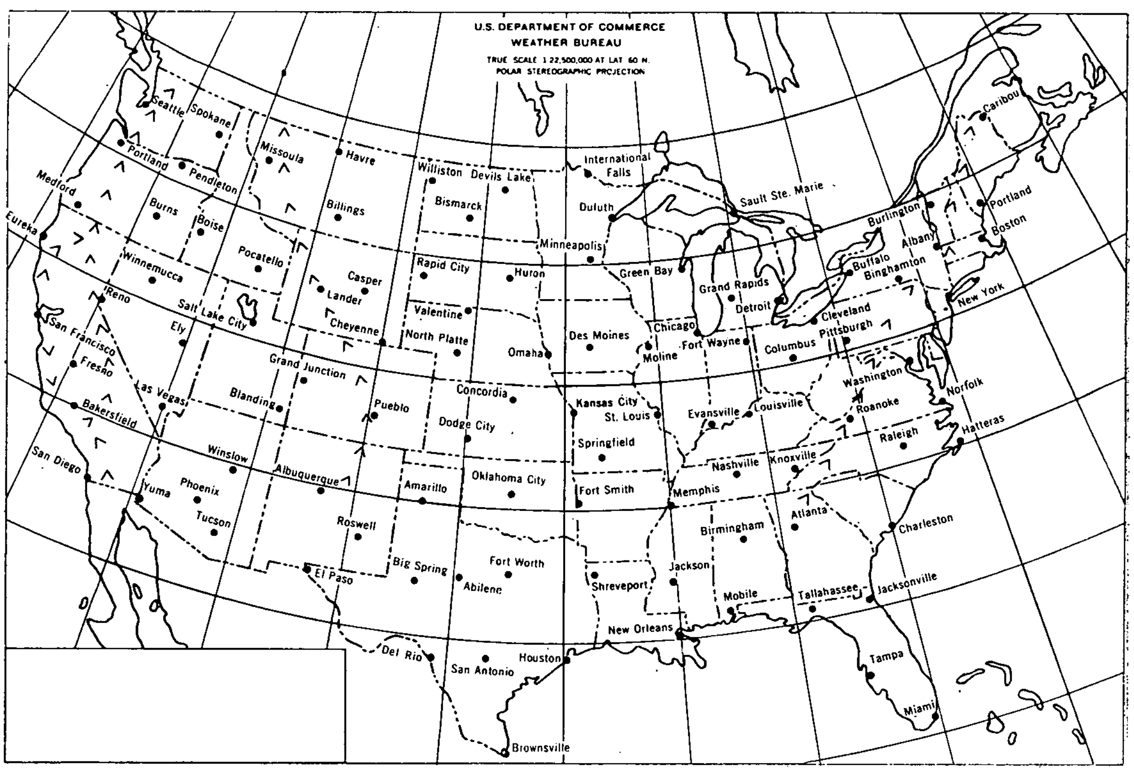

FIGURE 20.—Network of 100 stations over the United States, for which temperature and precipitation forecasts are verified.

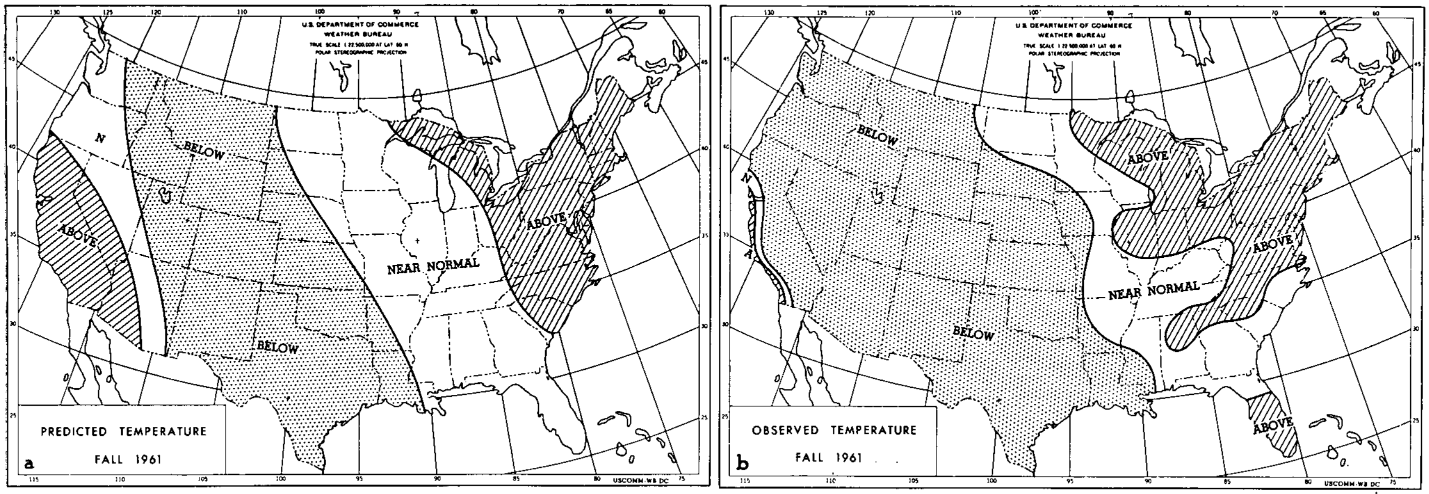

FIGURE 21.—Example of (a) a good temperature prediction and (b) the observed pattern.

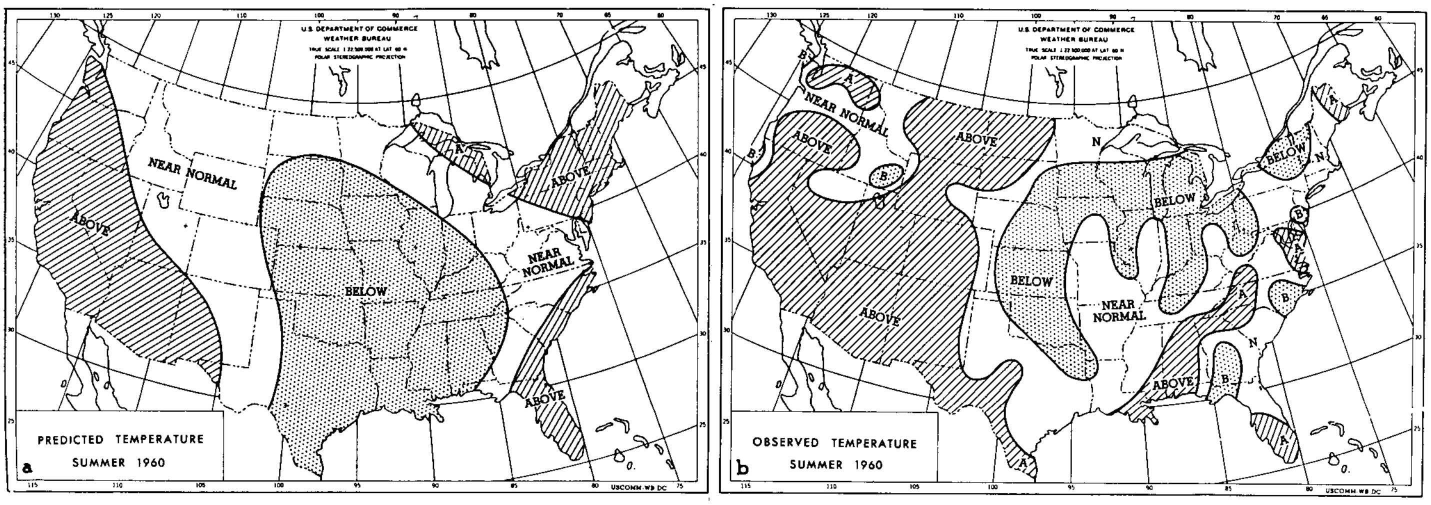

FIGURE 22.—Example of (a) an average temperature prediction and (b) the observed pattern.

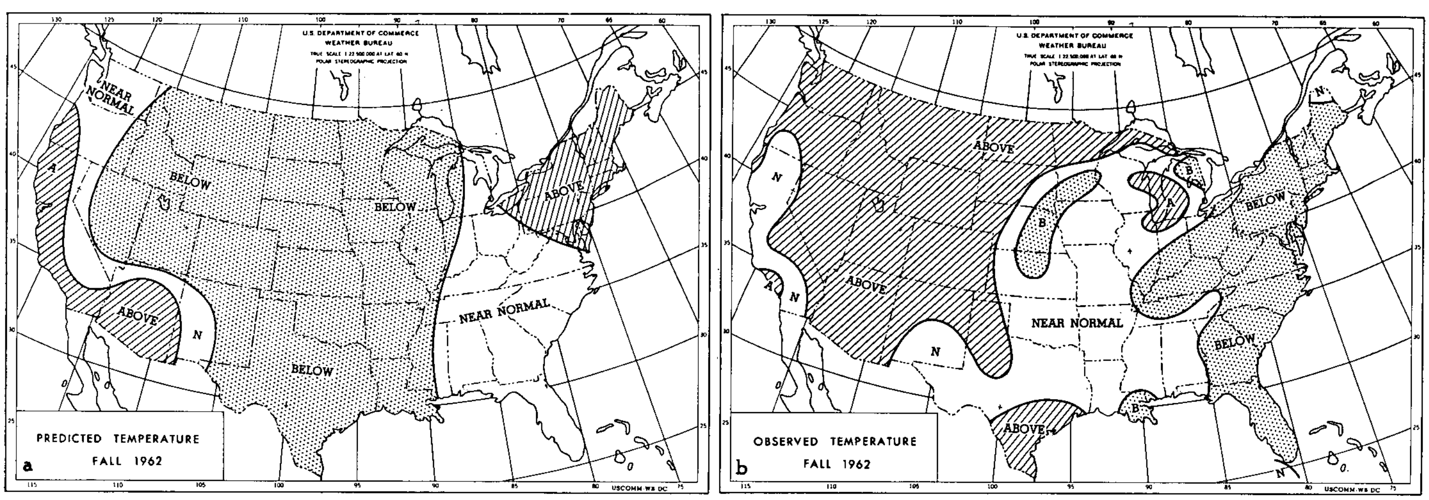

FIGURE 23.—Example of (a) a poor temperature prediction and (b) the observed pattern.

results justified the assumption that the 19 skill scores were independent. The 19 skill scores for temperature yield a t-test value of 2.48 which with a one-sided critical region and 18 degrees of freedom would be adjudged significant at the 5-percent level. The t-value for precipitation was found to be 1.17, so that it would require about twice the present sample size to demonstrate skill at the same level of significance.

TABLE 3.—*Probability of achieving a forecast class for this data sample (2200 predictions)*

		Temperature forecast						Precipitation forecast			
		Below	Normal	Above	Observed			Light	Moderate	Heavy	Observed
Percent frequency of occurrence	Below	47	38	27	38	Percent frequency of occurrence	Light	39	34	30	34
	Normal	25	28	28	27		Moderate	31	34	35	33
	Above	28	35	45	35		Heavy	30	32	35	33

TABLE 4.—*Distribution of seasonal temperature forecast skill scores by season, winter 1959–spring 1964 (22 seasons)*

	Forecast	Persistence
Winter	15	3
Spring	4	−9
Summer	13	16
Fall	10	0
Annual	10.5	2.1

Correlation between forecast skill and persistence skill = −0.17.

From table 1 it was determined that the correlation between forecast skill and persistence skill was −0.17, so that the positive skill obtained cannot reasonably be attributed to persistence.

From tables 2 and 3 it is clear that the skill in seasonal prediction lies in the extreme classes, both for temperature and precipitation. In other words, near normal predictions of either element were not successful. While reasons for this are not entirely clear, it appears to indicate that at present only general patterns of anomaly can be prognosticated and that shifts in these patterns one way or another take place more easily in the narrow "buffer zone" of the near normal area, usually sandwiched between the two extreme categories.

7. SUMMARY AND OUTLOOK

In this report the author has attempted to show that even elementary procedures may yield a partial solution of the seasonal forecast problem. These procedures involve:

1. Data processing and analysis of sea level and mid-tropospheric material on time scales of months, seasons, and years.

2. Statistical treatment by autocorrelation of the above data and portrayal of regression predictions on a macroscopic (hemispheric or half-hemispheric) scale.

3. Employment of statewide seasonal temperature (and occasionally precipitation) contingencies, plotted as a nationwide pattern.

These indications are then studied against the background of internal consistency (both physical and statistical), suggested interactions between temperature and circulation patterns on synoptic and planetary scales, and past analogy and experience.

The final products are predicted patterns of temperature anomaly and precipitation classes for the contiguous United States.

Future plans include the employment of more complex statistical-physical methods, and the development of a numerical model in which the causes of seasonal abnormalities are introduced. These causes are believed to be found in complex feedback mechanisms between the atmosphere and the characteristics of the underlying continents and oceans. Details of this attack and results of the first model of this sort may be found in a paper by my colleague, Dr. Julian Adem [1].

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